(122)

Copy

# NASA PROJECT APOLLO WORKING PAPER NO. 1020

PROJECT APOLLO

A PRELIMINARY STUDY OF A FIN-STABILIZED SOLID-FUEL ROCKET BOOSTER FOR USE WITH THE APOLLO SPACECRAFT

[redacted]

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE TASK GROUP

Langley Field, Va.

June 7, 1961

NASA PROJECT APOLLO WORKING PAPER NO. 1020

# PROJECT APOLLO

# A PRELIMINARY STUDY OF A FIN-STABILIZED SOLID-FUEL ROCKET BOOSTER FOR USE WITH THE APOLLO SPACECRAFT


Prepared by: Alan B. Kehlet

Alan B. Kehlet
Asst. Head, Flight Dynamics Branch

Richard F. Smith

Richard F. Smith
Head, Equipment Engineering Section

Edward E. Mayo

Edward E. Mayo
AST, Flight Mechanics

John E. Canady, Jr.

John E. Canady, Jr.
AST, Flight Systems


Authorized for Distribution:

Robert R. Gilruth

Robert R. Gilruth, Director


NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

SPACE TASK GROUP

Langley Field, Va.

June 7, 1961

# TABLE OF CONTENTS

# LIST OF FIGURES

# A PRELIMINARY STUDY OF A FIN-STABILIZED SOLID-FUEL ROCKET BOOSTER FOR USE WITH THE APOLLO SPACECRAFT


## SUMMARY

A preliminary study has been conducted on a fin-stabilized, solid-fuel rocket booster for use with the Apollo reentry spacecraft. The study was based on seven guidelines which were generated as a result of experience with the Project Mercury spacecraft and the Little Joe booster. The results from the study indicated that the guidelines were not difficult to meet with the proposed booster configuration. Sufficient information is presented to enable the calculation of launch trajectories using the Little Joe Senior booster with any defined spacecraft payload.


## INTRODUCTION

A preliminary study has been conducted on a fin-stabilized, solid-fuel rocket booster for use with the Apollo spacecraft. The booster, as conceived, is capable of propelling a full-scale Apollo reentry spacecraft to velocities sufficient to match critical portions of the Saturn trajectory. The purposes of this booster are to provide a simple and fairly inexpensive means of determining from flight tests, full-scale configuration concepts, systems hardware performance, vehicle structural integrity, and flight crew training behavior. Since the Apollo mission will require the use of multistage launch vehicles, aborts will have a higher probability of occurrence than in the Mercury mission. Of particular importance then is the flight testing of the Apollo spacecraft escape system under simulated maximum conditions.

The fin-stabilized, solid-fuel rocket booster studied and proposed in this paper is about a twice-size-copy of the highly successful Project Mercury Little Joe booster. Because of the similarity, the booster presented herein will be referred to as Little Joe Senior. The Project Mercury Little Joe booster was designed, built, and flight tested in less than 1 year from concept. The reason for this remarkable performance was the simplicity of the approach. The same type of philosophy is applied to Little Joe Senior. The Project Mercury Little Joe booster not only proved the Mercury escape system concept and structure, but also pointed out flaws in the sequence design. In addition, vehicle dynamics, operational handling problems with the full-scale capsule, and animal behavior under acceleration and weightlessness were determined. It is anticipated that similar flight data on the Apollo configuration with the Little Joe Senior could be obtained.

The preliminary study described herein was based on the following guidelines:

(a) The booster airframe was to resemble Little Joe.

(b) The propulsion was to be multiple use of the Scout first-stage rocket motor.

(c) With a 10,000 payload, the booster should be capable of achieving Mach number 2 at 1,200 pounds per square foot dynamic pressure.

(d) A dynamic pressure of 1,600 to 1,800 pounds per square foot at supersonic speeds was to be within booster performance capabilities.

(e) A maximum Mach number 4 was to be obtained.

(f) The booster was to be capable of flying a zero-lift trajectory without the use of an attitude control system.

(g) The airframe was to be designed to accommodate any number up to 7 rocket motors without using the rocket cases as load-carrying members.

These guidelines were formulated as a result of experience with the Project Mercury spacecraft and the Little Joe booster. The scope of the preliminary study conducted and presented in this paper was detailed enough to show that the guidelines are not difficult to meet; however, a complete design of the Little Joe Senior booster was not attempted. Sufficient information is provided herein to enable the calculation of launch trajectories with any size and weight payload as well as to complete the booster, launcher and service tower design.

## SYMBOLS

$C_A$ axial-force coefficient, $C_{A,T} - C_{A,b}$

$C_{A,b}$ base axial-force coefficient, $\frac{\text{Base axial force}}{qS}$

$C_{A,T}$ total axial-force coefficient, $\frac{\text{Total axial force}}{qS}$

$C_D$ drag coefficient, $C_A \cos \alpha + C_N \sin \alpha$

$C_{D,\alpha=0}$ drag coefficient at $\alpha = 0^{\circ}$

$C_N$ normal-force coefficient, $\frac{\text{Normal force}}{qS}$

$C_{N_{\alpha}}$ normal-force curve slope per degree at $\alpha = 0^{\circ}$, $\frac{\partial C_N}{\partial \alpha}$

$\alpha$ angle of attack

C.P. center of pressure

$\theta_o$ launch angle, deg

## DISCUSSION OF STUDY

### Launch Configuration

The Little Joe Senior configuration booster and spacecraft arrangement proposed, shown in figure 1, consists of three major sections: the payload, the adapter, and the booster. The booster is designed to accommodate any number up to seven Algol (first-stage Scout) solid-propellant rocket motors. The physical characteristics of the configuration are dependent on the number of rocket motors installed and upon the staging or firing order of the motors. Table I shows a tabulation of weights, centers of gravity, and inertias of the vehicle for various flight programs. Table II shows a weight and center of gravity summary of the major sections loaded with seven Algol rocket motors.

### Payload

The payload for Little Joe Senior is considered to be an Apollo-type spacecraft weighing about 10,000 pounds. The spacecraft is comprised of three sections: the escape tower and rocket, the capsule proper, and the retropackage.

The escape rocket and tower combination utilize a quick-release device for separation from the capsule. Jettisoning of the escape tower occurs at booster burnout before capsule separation during normal flights, and after capsule separation during abnormal flights when abort from the booster is desired.

The capsule proper is chiefly a pressure vessel which may be manned for training flights or to carry instruments only for experimental flights.

The third section of the payload is the retropackage, attached to the heat shield and jettisoned after use in flight.

## Adapter

The 10-foot long adapter section between the booster and capsule has sufficient space to accommodate the retropackage, the umbilical, booster equipment, and other spacecraft propulsion systems. The adapter is vented to prevent high loading on the capsule-adapter joining clamp from pressure which would be trapped in an unvented adapter at high altitudes.

## Booster

The Little Joe Senior booster is about 42 feet long, including fins, and 13 feet in diameter. The four stabilizing fins, shown in figure 1, have $45^{\circ}$ leading edge sweep angles and a total surface area of 150 square feet per fin.

The booster will accommodate up to seven Algol rocket motors, which may be programed as shown in table I. The rocket cases are considered to be nonstructural, thus allowing motors to be eliminated to change performance characteristics. Thrust is transmitted into the airframe at the nozzle end of the rocket motors and axial expansion is controlled at the upper end.

The booster body is comprised of two sections, the forebody and the afterbody.

The forebody extends from station 255.1 to station 482.1 as shown in figure 1. Its structure is an aluminum alloy monocoque cylindrical shell bounded at each end by structural rings. A light upper ring is employed in joining the adapter to the booster. Another ring forming an upper bulkhead is utilized to support the rocket motors laterally and also to support the upper end of the configuration for attachment to the launcher. Pressure seals are provided to seal the slip joint formed by motors and bulkhead. These seals are necessary in maintaining pressures higher than ambient in the booster for structural integrity. A lower ring at station 482.1 serves as the parting joint for assembly purposes.

The primary forces on the booster imposed by fins, rocket motors, and aerodynamic loading, are concentrated on the afterbody structure from station 482.1 to station 605.1. The structure of the afterbody consists of a cylindrical aluminum alloy shell which houses a pressure-tight motor support bulkhead. Mounting sockets for supporting the booster on the launcher are provided in the afterbody structure.

The structure of the booster fins is of typical aircraft construction having an aluminum skin. Each fin has a root fitting for quick attachment to the booster body.

An estimated weight and center-of-gravity breakdown of the booster airframe is given in table II.

## Rocket Grain Temperature Control

To perform satisfactorily, the Algol rocket motor propellant must be maintained at a temperature of 70° F to 90° F before flight. This is accomplished by providing hatches for attaching ducts to the upper and lower extremities of the booster shell through which conditioned air from a heat exchanger is circulated. Thermocouples within the propellant grain automatically control the temperature.

## Little Joe Senior Launcher and Service Tower

Experience with the launching operations of the Project Mercury Little Joe has indicated that the Little Joe launcher was satisfactory; however, the absence of a ground service tower made booster and capsule assembly and checkout difficult. A preliminary "look" into launcher and service tower design has been completed as part of the Little Joe Senior study. The launcher proposed is very similar to the Mercury Little Joe design. The service tower is a covered, roll-away structure which incorporates many features found desirable from Mercury experience.

### Launcher

The proposed launcher for Little Joe Senior, shown in figure 2, is a 60,000-pound fabricated steel structure mounted on a concrete foundation. The launcher is remotely adjustable in pitch and azimuth positions. Azimuth adjustment is ±45° and pitch adjustment is 20° from the vertical position.

The launcher is comprised of seven major components: umbilical arm, mast, support assembly, pivot frame, support struts, base, and remotely operated self-locking actuators. Structural components are to be provided with ample heat-sink capacity to safely absorb rocket-motor heat. Other components are to be shielded from the heat. Azimuth adjustment is provided by an actuator which rotates the pivot frame. Pitch adjustment is provided by actuators built into the support struts. The mast serves two functions: one, to support the upper portion of the booster, the other, to support the pivoting arm which pulls the umbilical connector from the capsule. A service ladder is also provided as an integral part of the mast. Provisions are made for the installation of a removal work platform mounted to the support assembly for installation of the rocket motors and nozzles.

## Service Tower

The ground service tower, in which the booster and payload are assembled on the launcher, is shown in figure 3. This tower is of structural steel construction totally enclosed with sheet metal and translucent panels to emit light, and is approximately 50 feet square and 100 feet high. The service tower is mounted on electrically driven wheels which ride on a pair of rails embedded flush in the concrete pad. This mobility allows the tower to be quickly removed away from the launcher before launching. Pads mounted on concrete anchor blocks are located at each end of the rails to provide two rigid tie-down locations for the service tower. One side of the tower is provided with a 34-foot wide by 90-foot high motorized door which allows the tower to clear the launch configuration while being removed. A 34-foot wide by 16-foot high service door is provided in the opposite end of the launcher to facilitate assembly. The following facilities are also provided with the service tower:

(a) An overhead traveling hoist which is capable of lifting 15 tons off the pad to an elevation of 90 feet above the pad.

(b) Work platforms that surround the launch configuration at various elevations: movement of these platforms to different levels is accomplished through use of the overhead hoist. These platforms are retracted to clear the launch configuration when moving the service tower away from the launch pad.

(c) An elevator to carry personnel, tools, and portable equipment to any elevation up to 90 feet above the pad.

(d) A ladder on the elevator side of the tower and a stairway on the opposite side.

(e) A heat exchanger with a flexible duct system to the booster. The function of this unit is to circulate conditioned air through the booster airframe, thereby maintaining a propellant grain temperature of $70^{\circ}$ F to $90^{\circ}$ F in the algol rocket motors.

## Booster Mission Capabilities

Shown in figure 4 are typical trajectory calculations of the Little Joe Senior booster. The trajectories illustrate the wide range of missions available with the six booster configurations shown in table I. Also included in figures 4(a) and 4(b) is the effect of launch angle. In all cases, the rocket motors were fired without a coast phase between stages. It should be noted that the lift-off accelerations are low and a detailed analysis of the effect of surface winds on the launch elevation and azimuth angles is now in progress. The use of a control system may be required. By varying the number of rocket motors and adjusting the launch angle, all the performance guidelines set forth in the "Introduction" section of this report can be met.

### Launch Vehicle Aerodynamics

The estimated static aerodynamics of the Little Joe Senior booster configuration with and without a payload are shown in figure 5. The estimated base axial-force coefficient at zero angle of attack is shown in figure 6. Through judicious use of figures 5 and 6 and with a new payload aerodynamics known, the estimated aerodynamics of the Little Joe booster configuration with any payload can be made. Since the Little Joe Senior booster closely resembles the Project Mercury Little Joe, the aerodynamics presented were obtained from reference 1 and modified through the use of references 2, 3, 4, 5, and 6. It should be noted that the booster is statically stable to Mach numbers close to 6, thus allowing the booster to fly a zero-lift trajectory without the use of a control system (wind-shear effects neglected).

### Rocket Motor Performance Characteristics

The performance characteristics and physical dimensions of the Algol (first-stage Scout) rocket motor are shown in figure 7. Pertinent information to enable the calculations of trajectories using this motor with the proposed airframe is included in the figure.

## CONCLUDING REMARKS

The results of a preliminary study of a fin-stabilized, solid-fuel rocket booster for use with the Apollo spacecraft indicate the following concluding remarks. The seven guidelines generated as a result of experience with the Project Mercury spacecraft and the Little Joe booster are not difficult to meet with the proposed boosting system. The airframe can be designed without the use of the rocket motors as load-carrying members and the configuration was calculated to be statically stable throughout the operational Mach number range. Because of the low lift-off accelerations, a detailed analysis on the effect of surface winds on launch angles is being presently conducted. Sufficient information is provided herein to enable the calculation of launch trajectories with any defined spacecraft payload.

# REFERENCES


1. Moseley, William C., Jr.: Project Mercury - Summary of the Longitudinal Stability Characteristics of the Mercury-Little Joe Configurations (M = 0.05 to M = 6.83). NASA Project Mercury Working Paper No. 114, Dec. 1959.

2. Rittenhouse, L. E. and Kaupp, H., Jr.: Influence of Several Shape Parameters on the Aerodynamics of Ballistic Reentry Configurations. AEDC-TR-60-15 (Contract No. AF 40(600)-800 S/A 11(60-110), Arnold Eng. Dev. Center, Dec. 1960.

3. McLellan, Charles H.: A Method for Increasing the Effectiveness of Stabilizing Surfaces at High Supersonic Mach Numbers. NACA RM L54F21, 1954.

4. Pitts, William C., Nielsen, Jack N., Kaattari, George E.: Lift and Center of Pressure of Wing-Body-Tail Combinations at Subsonic, Transonic, and Supersonic Speeds. NACA Rep. No. 1307, 1957.

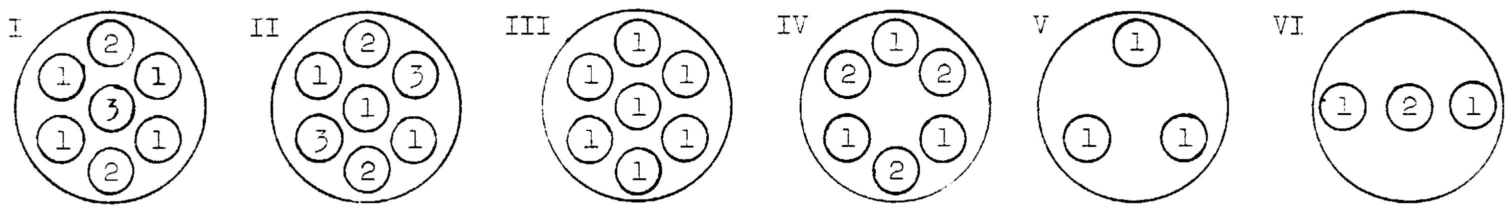
5. Brown, Steve W., and Moseley, William C., Jr.: Summary of Wind-Tunnel Investigations of the Static Longitudinal Stability Characteristics of the Production Mercury Configurations at Mach Numbers From 0.05 to 20. NASA TM X-491, 1961.

6. Ames Research Staff: Equations, Tables and Charts for Compressible Flow. NACA Rep. No. 1135, 1953.

TABLE I.- LITTLE JOE SENIOR - WEIGHT, CENTER OF GRAVITY AND MOMENTS

OF INERTIA FOR SIX BOOSTER CONFIGURATIONS

Sketches represent end views of booster configurations.




Numbers on rocket motors denote motors ignited for first, second and third stages.

| | At first-stage ignition | | At second-stage ignition | | At third-stage ignition | | *Moments of inertia at first-stage ignition | |
|---|---|---|---|---|---|---|---|---|
| | Wt. lb | C.G. sta. | Wt. lb | C.G. sta. | Wt. lb | C.G. sta. | Roll | Pitch-yaw |
| I | 178,800 | 418 | 102,100 | 412 | 63,800 | 404 | 110,000 | 734,000 |
| II | 178,800 | 418 | 121,300 | 414 | 83,000 | 409 | 110,000 | 734,000 |
| III | 178,800 | 418 | | | | | 110,000 | 734,000 |
| IV | 156,200 | 415 | 98,700 | 409 | | | 109,000 | 687,000 |
| V | 88,400 | 398 | | | | | 71,000 | 541,500 |
| VI | 88,400 | 398 | 50,000 | 376 | | | 60,000 | 525,000<br>547,000 |

*Slug-ft$^2$

Weight, center of gravity, and inertia figures are for the total configuration escape system, capsule, retropack, adapter, booster and so forth.

TABLE II.- LITTLE JOE SENIOR CONFIGURATION - WEIGHTS AND BALANCE STATEMENT

The tables below show a weight and balance statement of the complete configuration at take-off and burnout of seven Algol rocket motors:

At take-off

| Item | Weight (lb) | Arm (in.) | Moment (in.-lb) |
|---|---|---|---|
| Capsule with escape tower, escape rocket, and retropack | 9,885 | 21.6 | 213,400 |
| Adapter with pressure plate | 1,835 | 190.1 | 349,000 |
| Booster loaded with 7 Algol rocket motors | 167,061 | 445 | 74,390,000 |
| Summary for total configuration | 178,781 | 418 | 74,952,400 |

At burnout

| Item | Weight (lb) | Arm (in.) | Moment (in.-lb) |
|---|---|---|---|
| Capsule with escape tower, escape rocket, and retropack | 9,885 | 21.6 | 213,400 |
| Adapter with pressure plate | 1,835 | 190.1 | 349,000 |
| Booster with 7 burned-out Algol rocket motors | 32,843 | 517 | 16,990,000 |
| Summary for total configuration | 44,563 | 394 | 17,552,400 |

The table below lists a weight and balance breakdown of each major component of the configuration:

| Item | Weight (lb) | Arm (in.) | Moment (in.-lb) |
|---|---|---|---|
| Capsule | 6,375 | 115 | 733,000 |
| Escape tower and rocket | 2,550 | -107.9 | -276,000 |
| Retropack | 960 | 173. | 167,000 |
| Adapter with pressure plate | 1,835 | 190.1 | 349,000 |
| Booster body (without motors or fins) | 4,505 | 480.1 | 2,160,000 |
| Fins (4) | 4,370 | 625.1 | 2,730,000 |
| 1 Algol rocket motor (loaded)<br>(empty) | 22,598<br>3,424 | 438.1<br>505 | 9,928,571<br>1,728,571 |

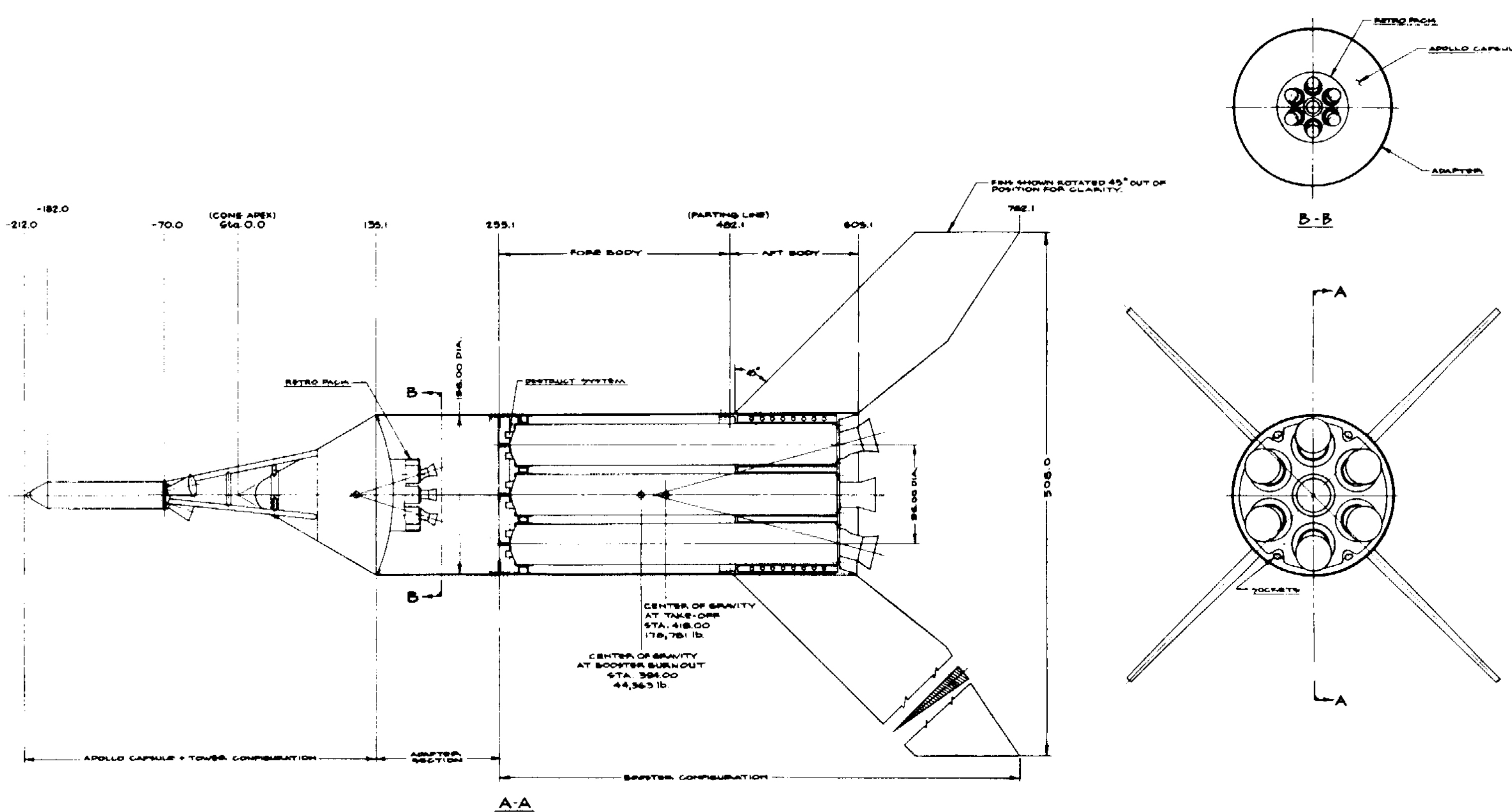



Figure 1.- General arrangement of Little Joe Senior booster and Apollo spacecraft.

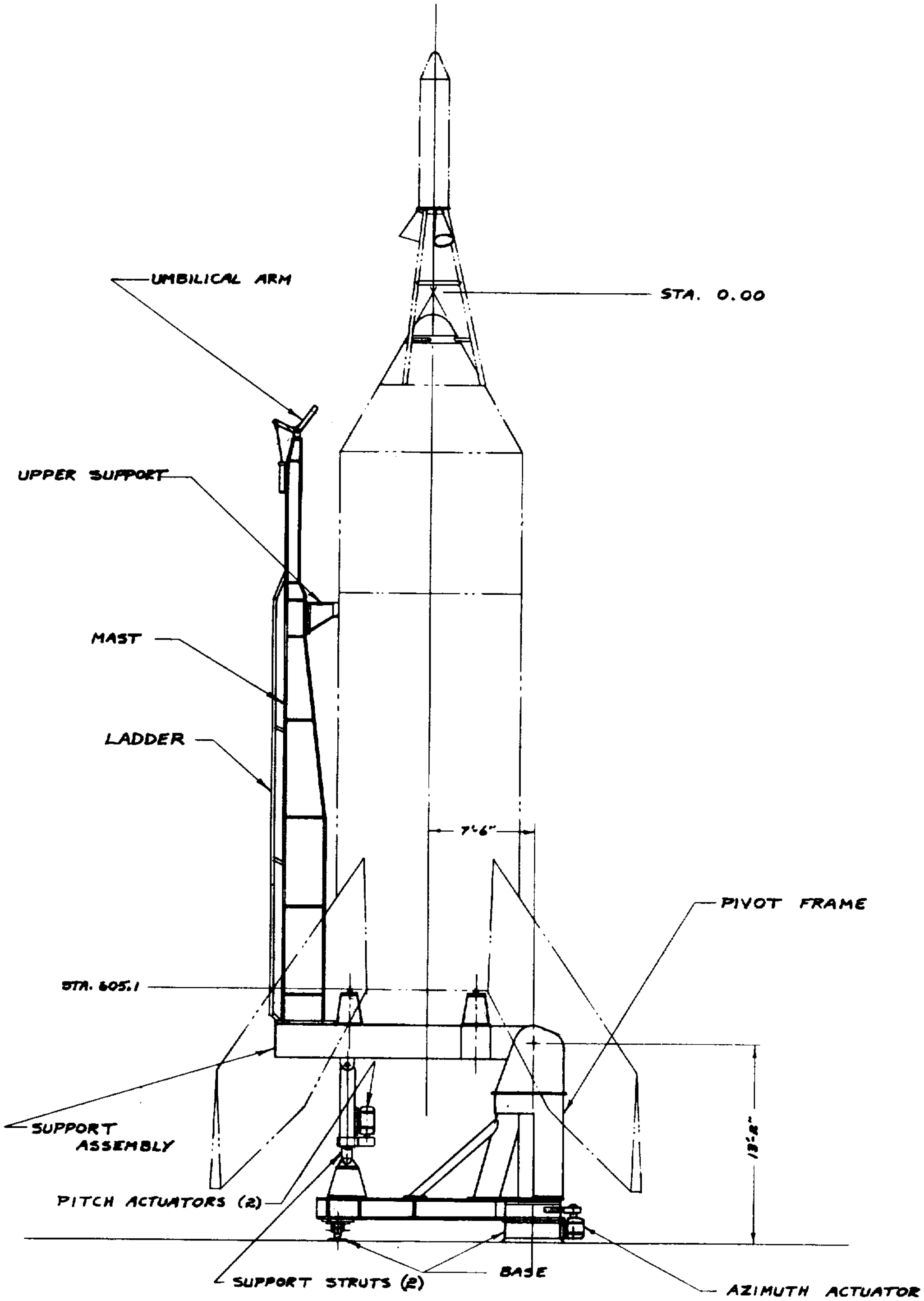



Figure 2.- Little Joe Senior launcher.

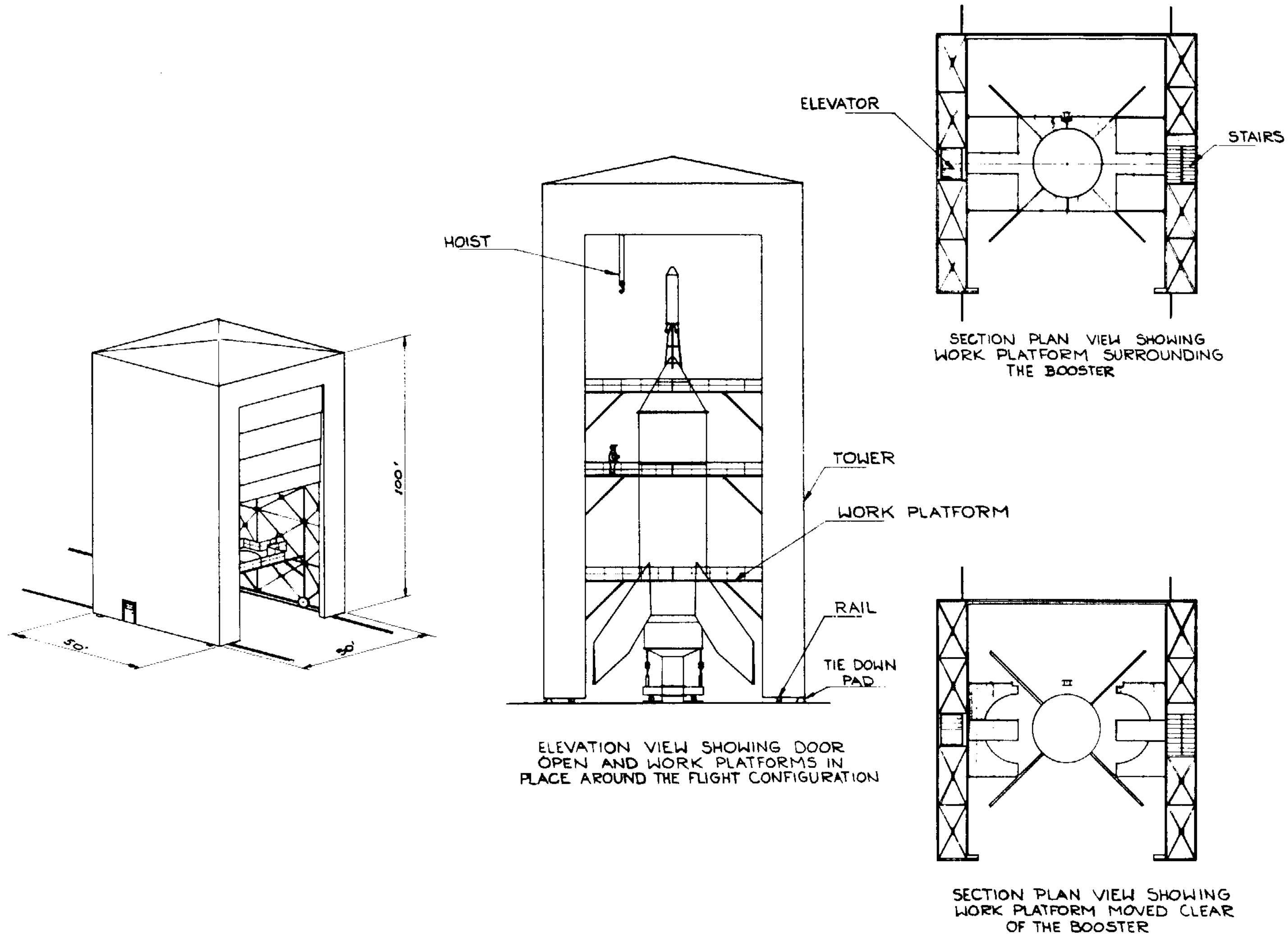
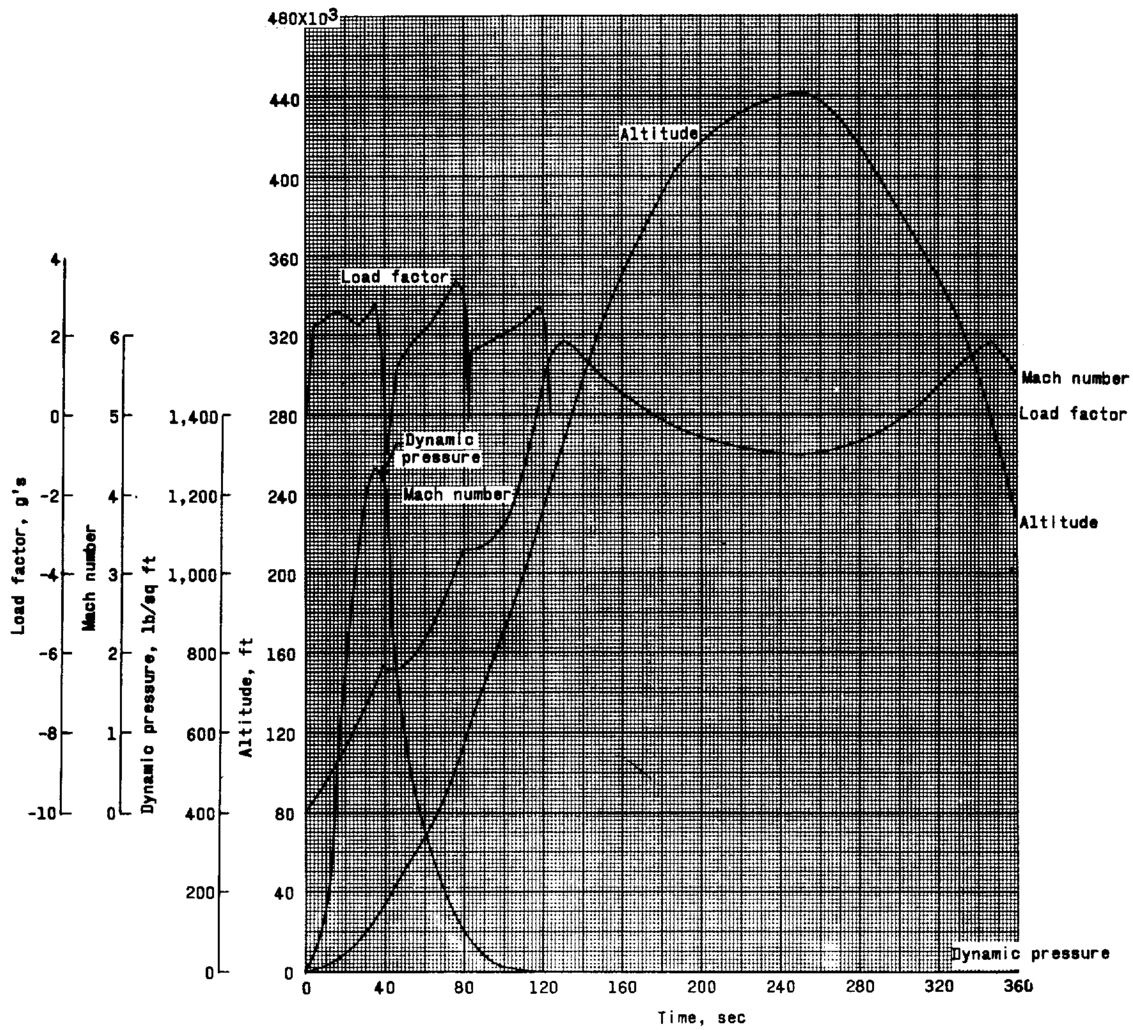
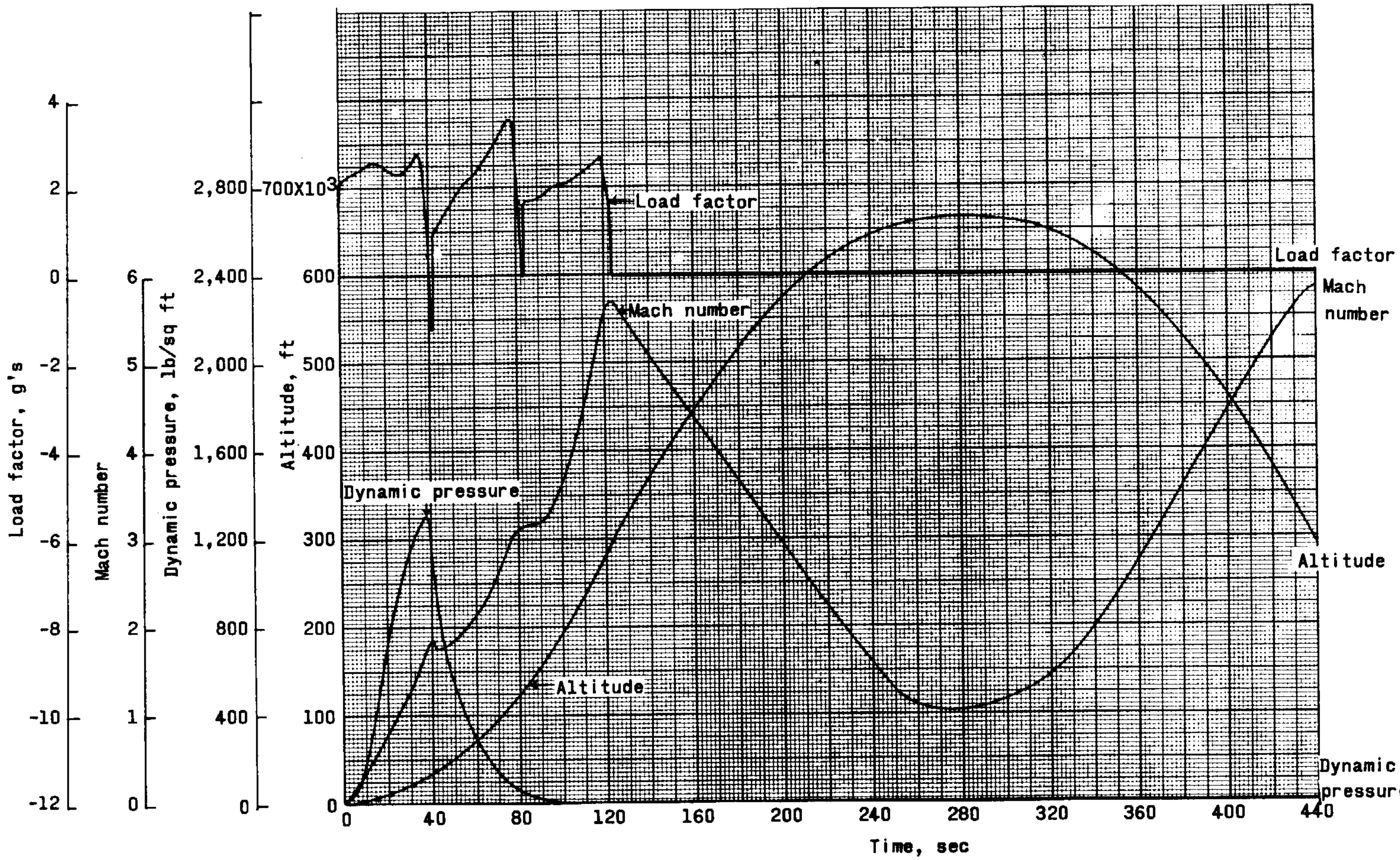



Figure 3.- Little Joe Senior ground service tower.



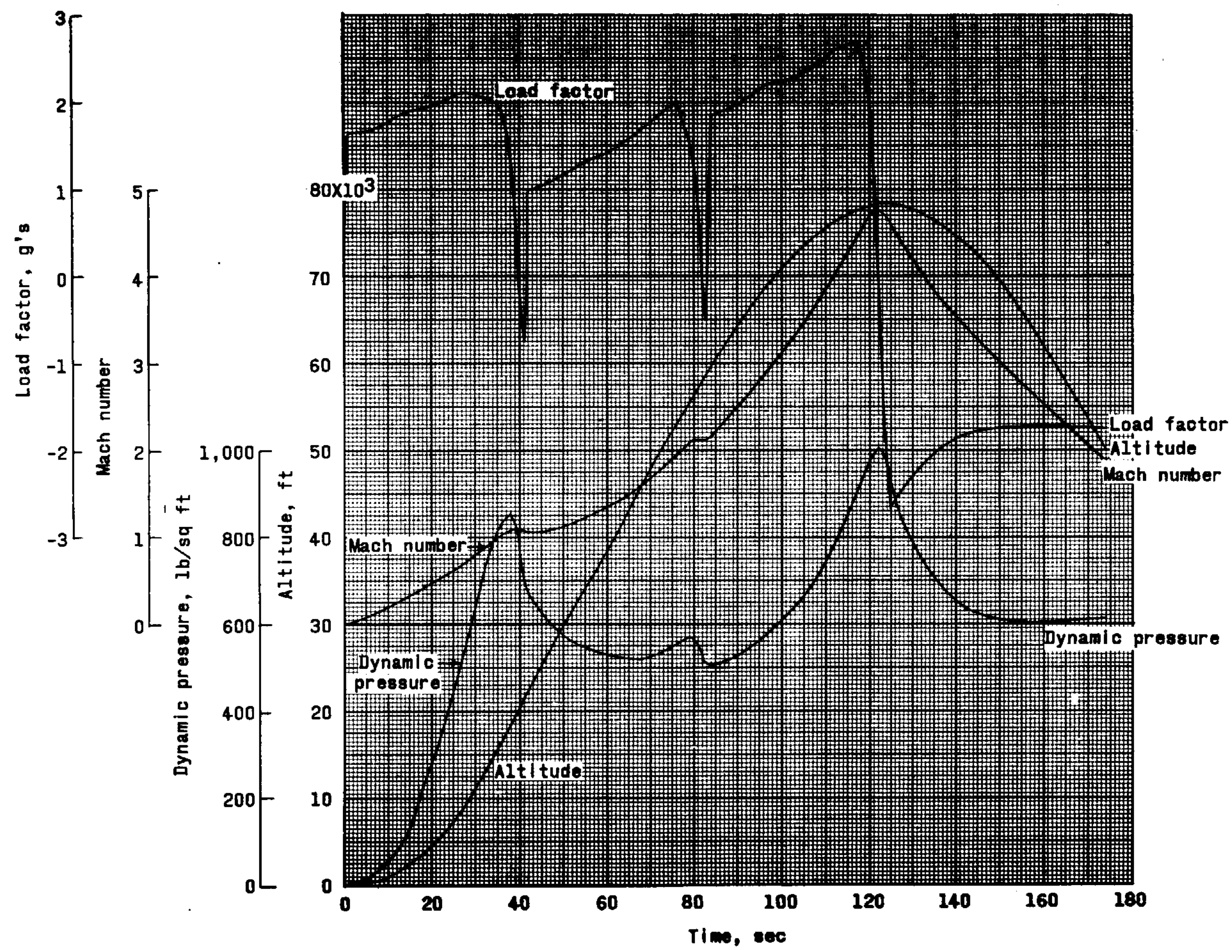

(a) Little Joe Senior Algol combination 4-2-1. $\theta_o = 85^\circ$.

Figure 4.- Typical trajectory calculations.



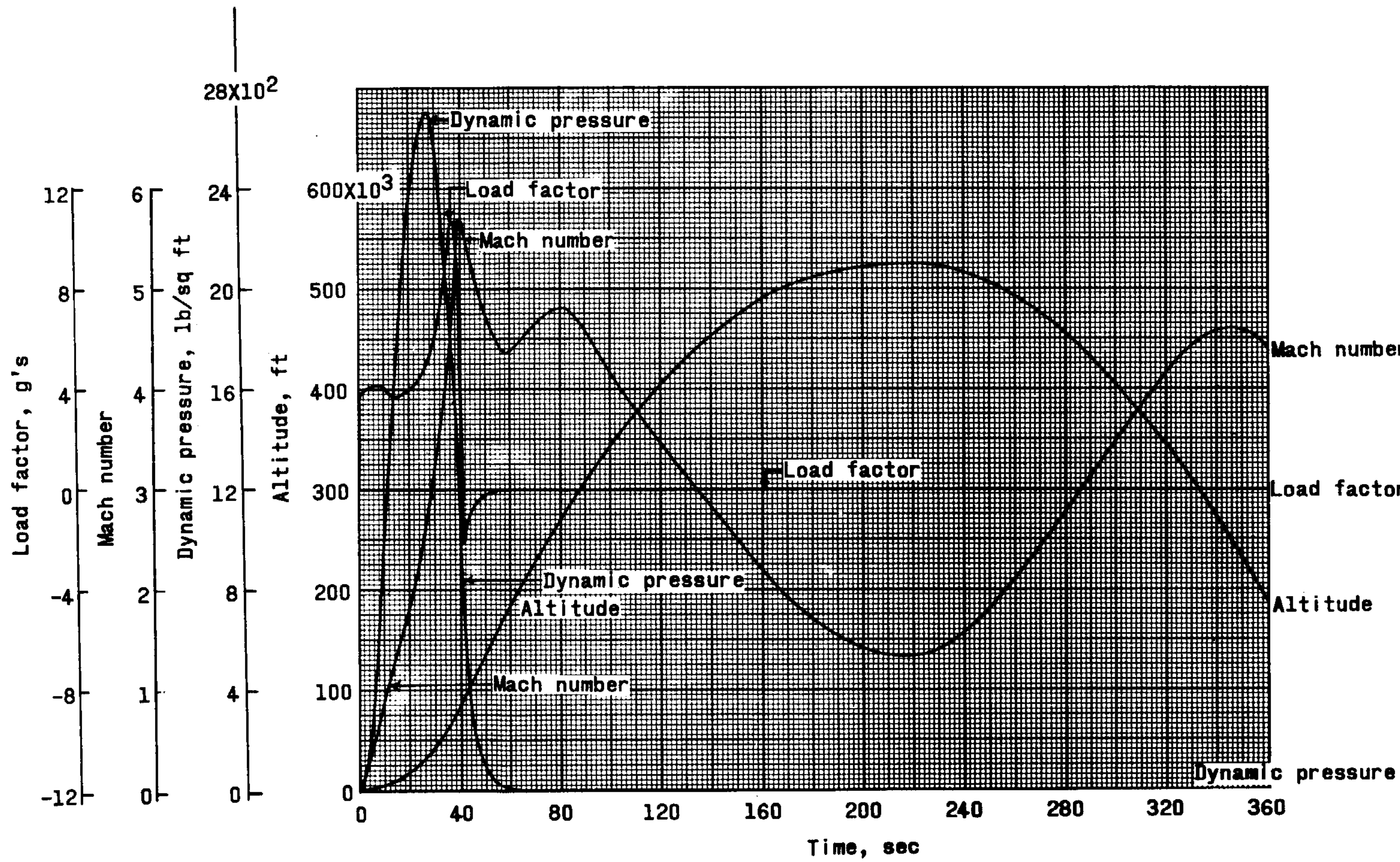

(b) Little Joe Senior Algol combination 4-2-1. $\theta_o = 89^{\circ}$.

Figure 4.- Continued.



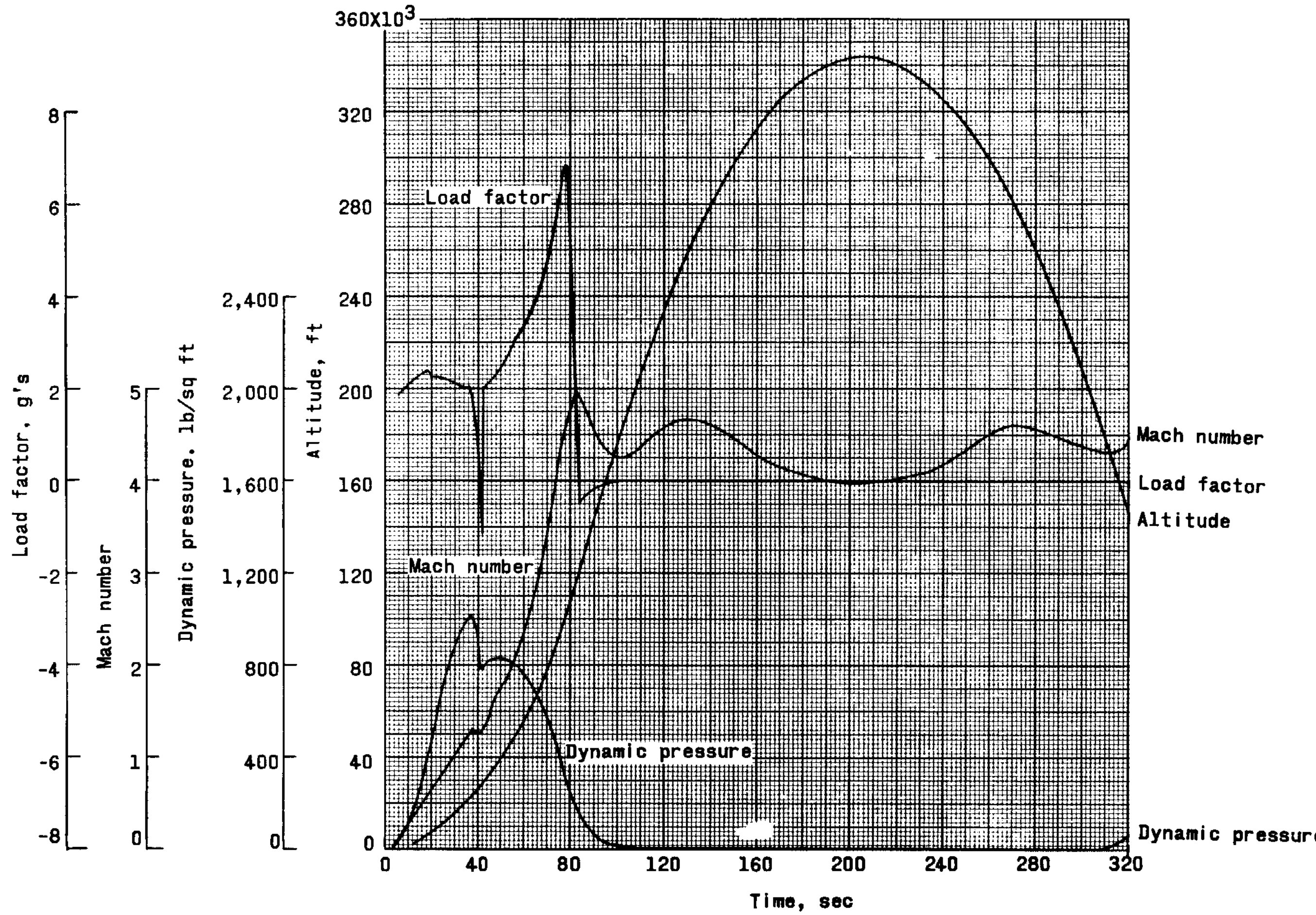

(c) Little Joe Senior Algol combination 3-2-2. $\theta_o = 85^\circ$.

Figure 4.- Continued.



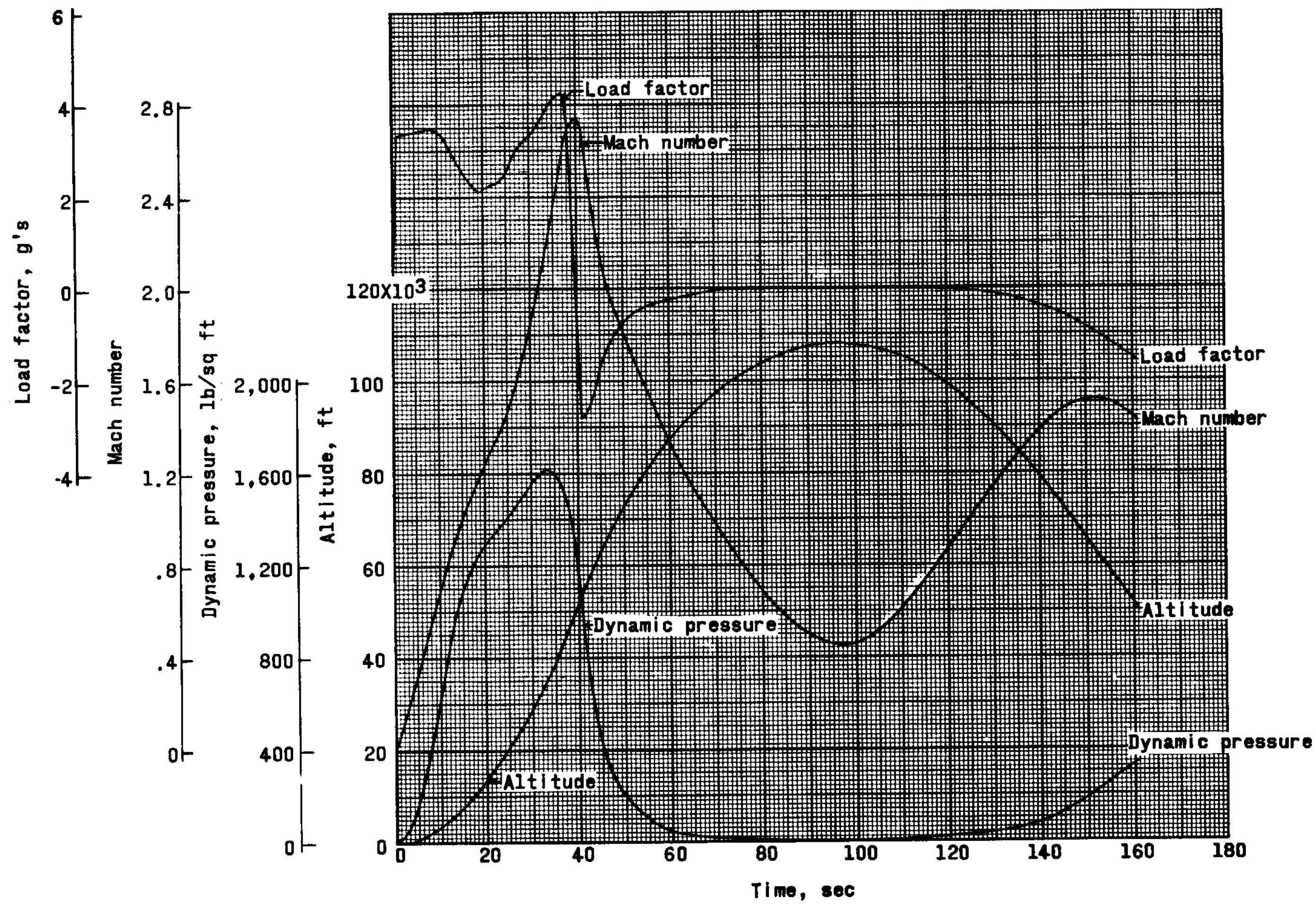

(d) Little Joe Senior Algol combination 7. $\theta_o = 85^o$.

Figure 4.- Continued.



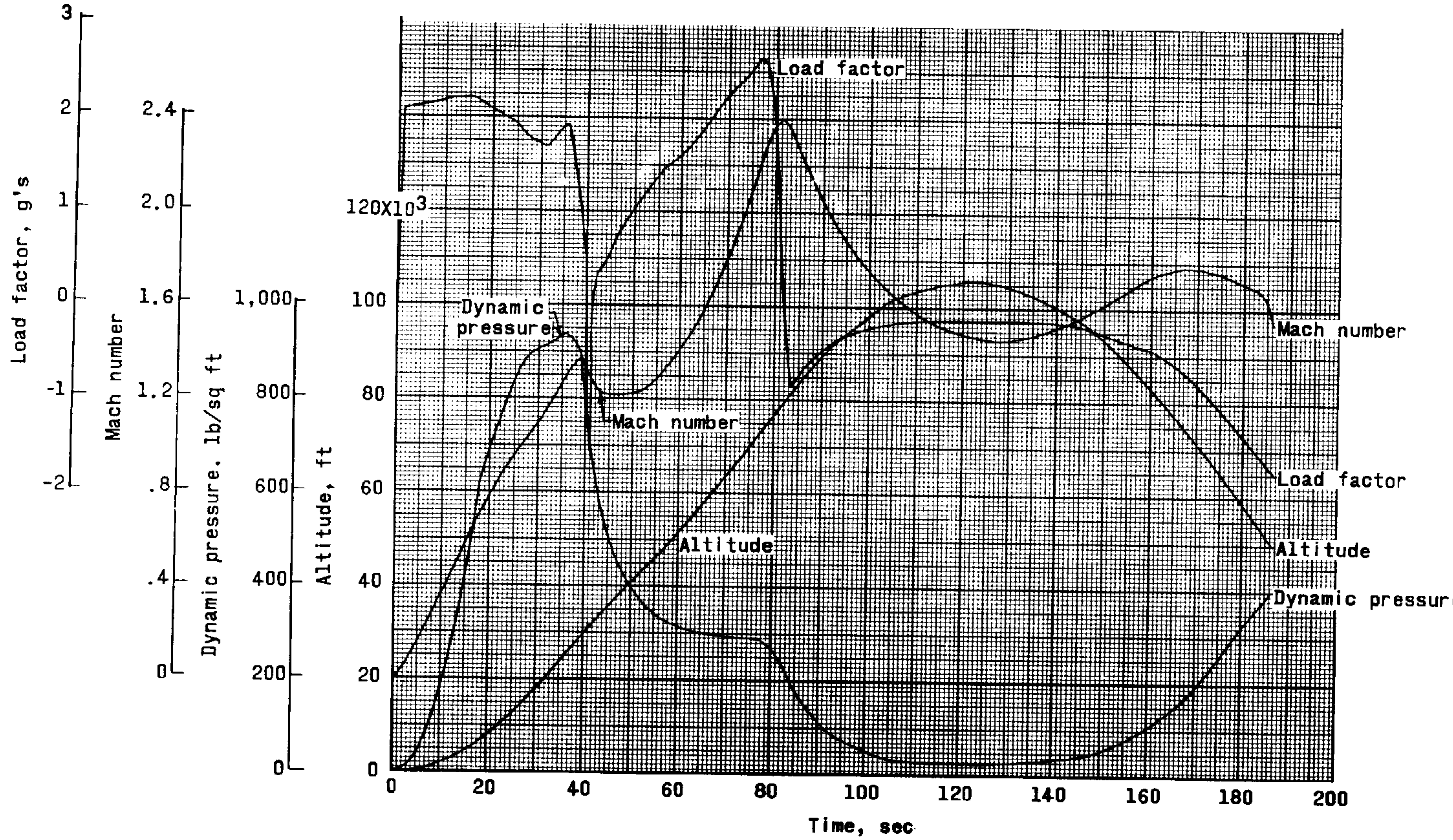

(e) Little Joe Senior Algol combination 3-3. $\theta_o = 85^\circ$.

Figure 4.- Continued.




(f) Little Joe Senior Algol combination 3. $\theta_o = 85^o$.

Figure 4.- Continued.




(g) Little Joe Senior Algol combination 2-1. $\theta_o = 85^\circ$.

Figure 4.- Concluded.

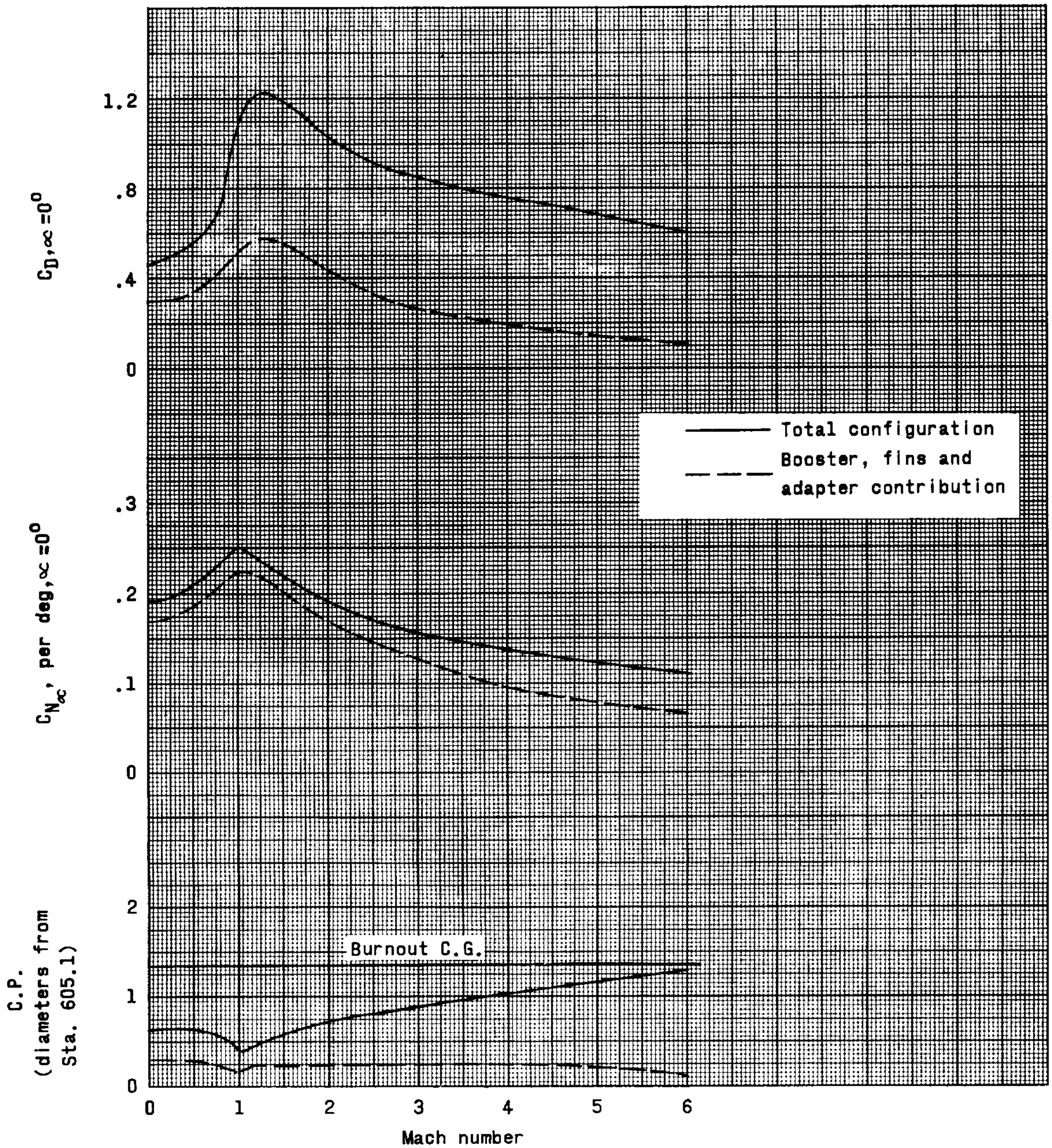



Figure 5.- Estimated longitudinal aerodynamic characteristics of Little Joe Senior.

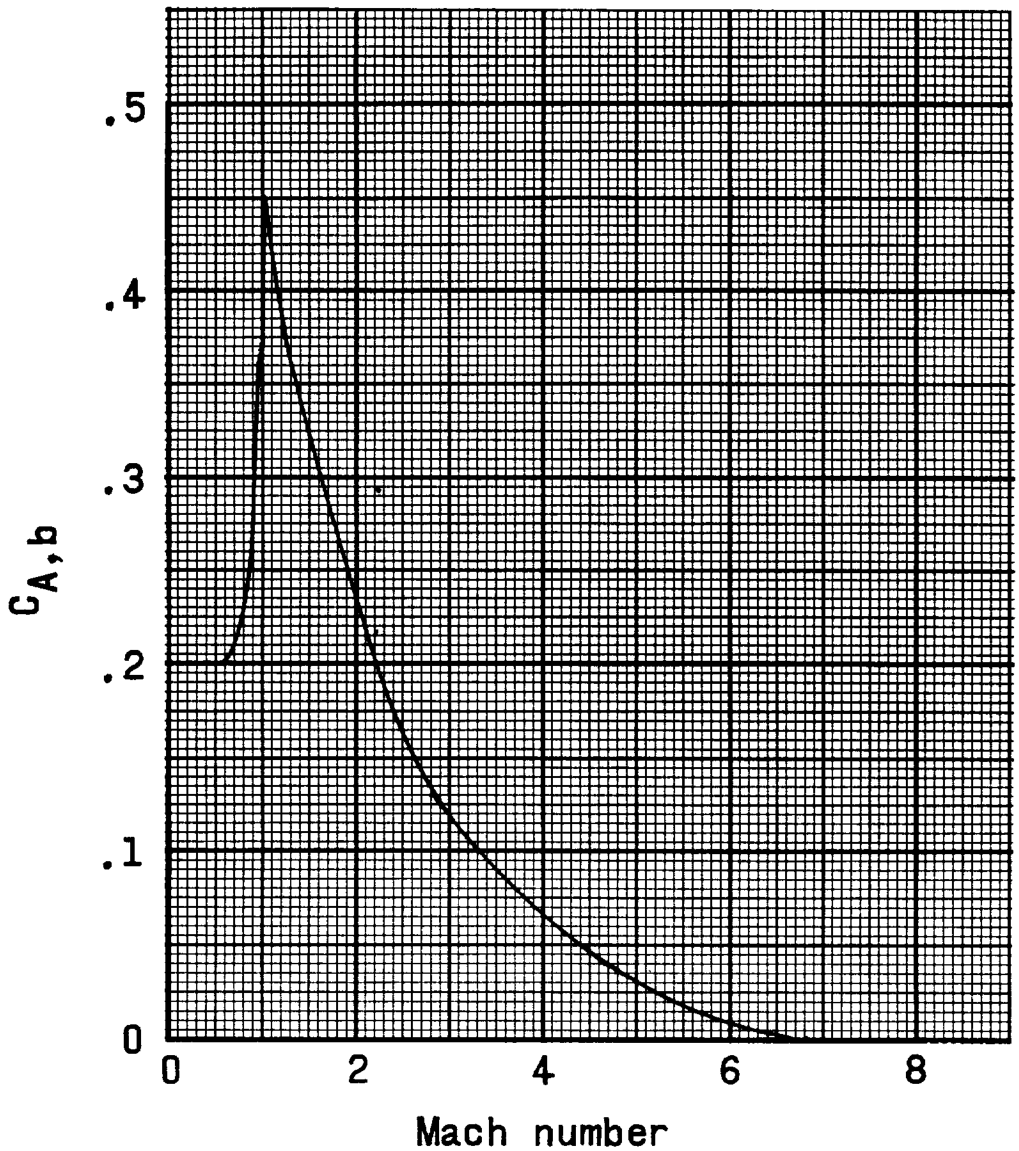



Figure 6.- Base axial-force coefficient at zero angle of attack.

Algol Nominal 2

$C_g$, loaded 166.47 in.
$C_g$, expended Mtr. 237.21 in.
Reference is forward thrust face.

Temp., °F 70
Nominal length, in. 357.6
Nominal diameter, in. 40.0
$\bar{e}_t$, in. 14.94
$d_e$, in. 32.19
$t_b$, sec 36.06
$t_t$, sec 41.29

$\int_{t_o}^{t_b} P_c\, dt$, psia-sec 15,488
$\int_{t_o}^{t_t} P_c\, dt$, psia-sec 16,980
$\bar{P}_b$, psia 429
Motor Loaded wt., lb 22,648
Consumed w., lb 19,205
Propellant wt., lb 18,998
Motor Expended wt., lb 3443

Sea-level performance

$I_b$, lbf-sec 3,713,400
$I$, lbf-sec 4,077,800
$\bar{F}_b$, lbf 102,980
$I_{sm}$, lbf-sec/lbm 180
$I_{sp}$, lbf-sec/lbm 215

Vacuum performance

$I_b$, lbf-sec —
$I$, lbf-sec —
$\bar{F}_b$, lbf —
$I_{sm}$, lbf-sec/lbm —
$I_{sp}$, lbf-sec/lbm —

Equation to compute thrust at any atmospheric pressure, $P_a$, for an expansion ratio of 4.64 : $F_A = F_V (1 - \_\_\_\_ P_a/P_c)$
where $F_A$ is the thrust at any altitude, $F_V$ is the thrust in a vacuum, $P_c$ is the chamber pressure.

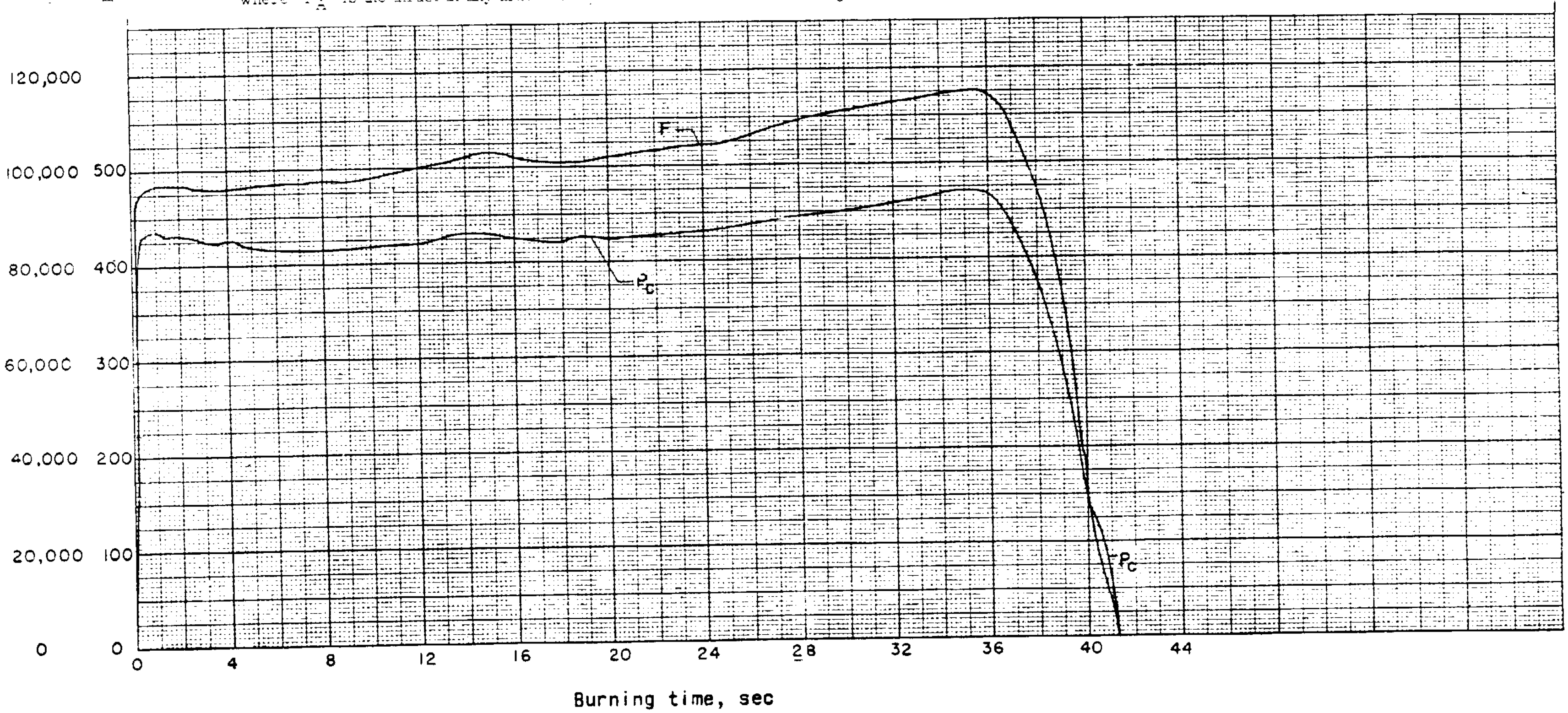



Figure 7.- Nominal thrust and chamber pressure histories of Algol (Senior) rocket motor.